GEOCHEMICAL AND STRUCTURAL COMBINATIONS IN THE ASSESSMENT OF UNDER-GROUNDWATER QUALITIES OF SOME EMERGING SETTLEMENTS IN IBADAN, SOUTHWESTERN NIGERIA

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Abstract
Efforts to monitor groundwater qualities in conjunction with its interaction with rocks and minerals are still in continuous process. The role of joints and fractures in the natural filtration process which aid the enhancement of underground water quality need to be examined. Therefore, the sub-surface structures together with the anisotropic properties of fractures and direction of underground water flow in the bedrock of four (4) emerging communities within Ibadan metropolis was investigated. One hundred and fifty seven (157) groundwater samples were collected, analyzed geochemically using Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) while square array method was adopted for investigating the structures. The pH values in the study area vary from 6.65-7.90 suggesting near neutral to alkaline nature of the water. The electrical conductivity (EC) vary from 107 μscm^{-1} to 551 μscm^{-1} this falls between the permissible level of World Health Organization. Higher carbonates-432 mgl^{-1} values than the WHO-340 mgl^{-1} standard indicate water hardness derived from carbonates mineral in the migmatite/gneissic rock. Total hardness a common property in Ibadan waters signifies water that is hard in terms of soap consumption and harsh in taste. The highest observed concentration for the TH is 563 mgl^{-1} which is above desirable limit (119 mgl^{-1}) of WHO-2004 for total hardness. Fractures orientation correlated adequately with the measurements of joints and fractures obtained during mapping exercise. These directions might have a connection to the direction of underground water flow it may also increase the vulnerability influence of the water to CO_3^{2-} and hardness. In conclusion, a reasonable hygienic culture and cleaning management should be imbibed in order to ensure safer water devoid of leachates that can be conducted through fractures into groundwater systems.

Key Words: *Groundwater, Potability, Harsh taste, Emerging settlements, Ibadan*

Introduction

Groundwater accounts for about 98% of the world's fresh water and it is fairly but evenly distributed throughout the world (Bouwer, 2002). Exploitation of groundwater from subsurface aquifers for private, domestic and industrial uses in many urban centers suffers drastic reduction in quality due to anthropogenic and geogenic influences, as it serves as the main receptor for many industrial and urban wastewaters, and for solid waste disposals (World Bank, 1998a). Pure water rarely occurs in nature due to the capacity to dissolve numerous substances which include heavy metals in large amounts. Industrial and urban wastewaters with leachates from solid waste materials which escape natural filtrations can be linked to underground-water sources through changes in a fracture system direction. A primary constraint for the use of groundwater is its quality. Population, rapid urbanization, industrialization, technological expression, energy utilization and waste generation from abattoir and industrial source have rendered many water sources unwholesome and hazardous to man and other living resources. Metals and metalloids get into the environment by air emissions from smelters, industrial smokes, waste incinerators, lead in household plumbing, old house paints and industrial waste (Tijani, 2000; Odewande and Abimbola, 2008).

There is the general perception that groundwater sources from shallow wells, open wells and boreholes are good for drinking and general household utilization. These are being utilized by the inhabitants of this area. Therefore, there is need to safeguard groundwater sources that can also get contaminated through the shallow geological structures which serve as conduits for water from surface to the aquiferous zones within the basement complex. If the lengths of these structures that serve as conduit pipe for the underground water is short, the natural processes of water filtration will be by-passed.

Since, under-groundwater has been observed as the major source of freshwater that provides for the domestic and industrial water demand which arise due to swelling or increase in population with modern agricultural practices in many developing countries. These resources can be derived from springs, shallow hand dug wells and boreholes because it is the only dependable freshwater in Nigeria that extend to the listed three demand sources where the need is required. Groundwater with intensive extractions has brought about both reduction in under-groundwater levels and quality. There are different types of water quality-related problems that can be linked to continuous extraction of groundwater resources. The effect of thickness and intensity of weathered soil profile on fresh basement rock have been investigated in many studies. Different geological structures which include joints, lineaments, fractures, faults and folds have played a major role in under-groundwater flow and quality-related problems. Also, the degree of presence and the arrangement of these structures have significantly controlled the quality. The geologic structures such as joints, lineaments, fractures and others act as both carriers and transporting routes for groundwater flow. Different studies have shown the role of structures in controlling the groundwater flow together with geology, drainage pattern and geomorphology in an area (Srinivasa and Jugran, 2003; Mondal *et al*., 2007; Al-Taj, 2008; Vasanthavigar *et al.,* 2011).

Changes in the orientation of joints and fractures can reduce or improve the filtration processes depending on the connections and condition surrounding this filtration processes. Also, precipitations and runoffs can also transfer contaminants to groundwater zones through this process. Weathering and mineral dissolution releases both anions and cations into water sources thereby affecting the quality. It is therefore crucial that periodic checks are performed on groundwater to establish its potability for consumption. This study emphasised on the appraisal of groundwater qualities and its potability with respect to geological structures as it affects groundwater contamination based on directional changes. Also, this was carried out to investigate the effects of geologic structures on groundwater movement and quality. The thickness and intensity of weathering will be studied from shallow wells lithologies, gather data and relevant information from river channel cuttings, and litho-sections from wells.

Study Area
Physiographic Setting

The study area covers about 625 km^2 with 07° 23′ N to 07° 30′ N and 003° 53′ E - 004° 00′ E as coordinates which is located in Ibadan SW Nigeria (Fig. 1). An irregular high topography characterized the area, dotted with hills and ridges but it experiences a tropical climate with two prevailing conditions at different times of the year. Annual temperature is approximately 27°C with 1500 mm to 1570 mm as mean rainfall while humidity is over 80% (Laniyan *et al.,* 2013). The drainage pattern is moderately dense and dendritic which may be mostly controlled by the structural trends within the crystalline rock terrain.

Geological Setting

Geologically, the study area lies within the Precambrian Basement Complex of Southwestern Nigeria. The major rock types that cover the area include: migmatites, banded and auguen gneisses, pegmatites, schists quartzites and amphibolites (Fig. 2). Surficial materials are characterized by relatively deeply weathered soil profile or regolith in the low lying areas due to high humid climatic conditions. Very high proportions of the soil cover are ferruginous tropical red soils (laterites) associated with Basement Complex terrains. In the area, soil degradation, weathering and soil erosion are commonly insignificant due to compactness of the surficial material. However, debris and weathered materials are washed along the slopes of the hills, this is a common phenomenon (Tijani and Onodera, 2009).
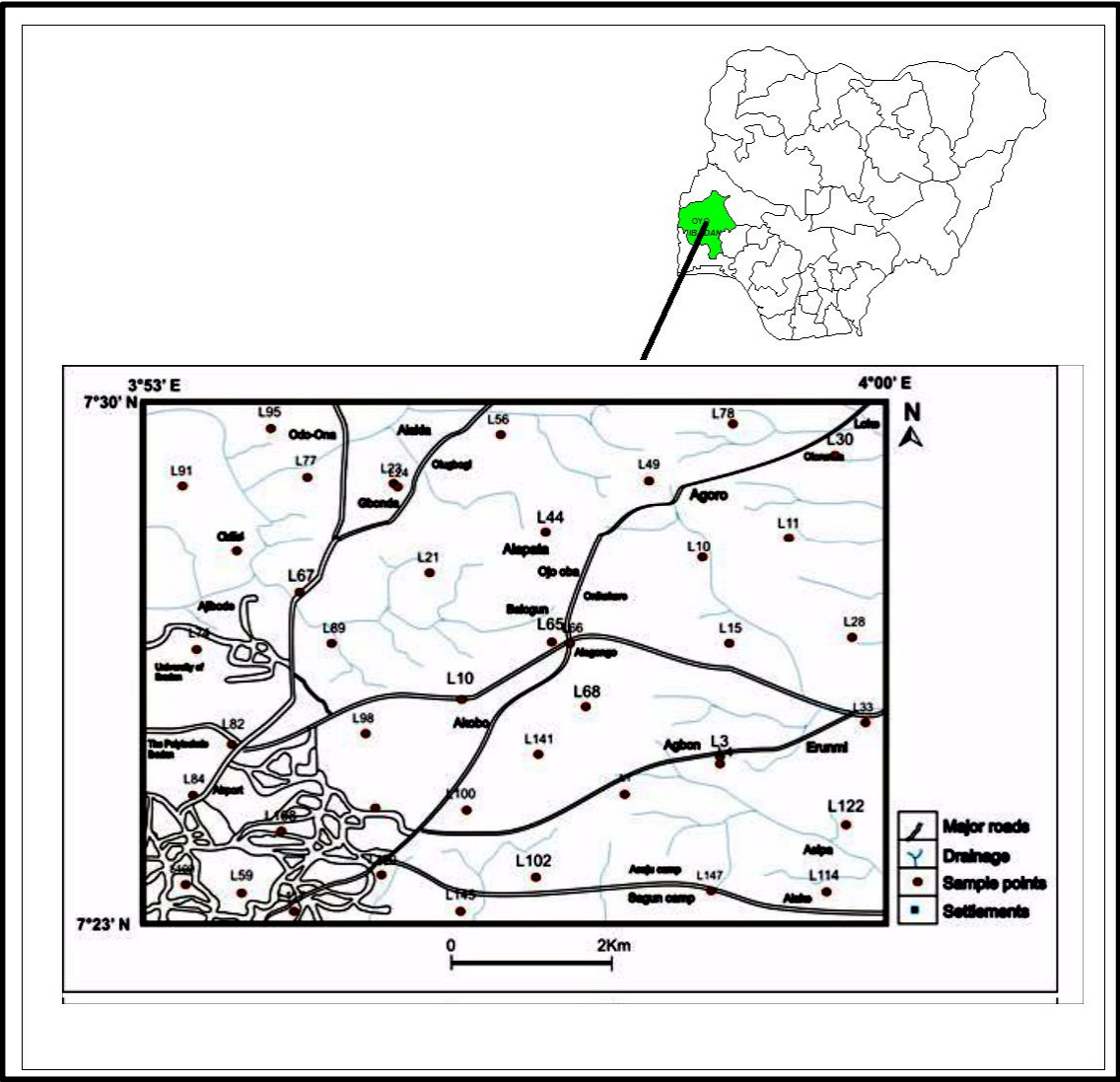
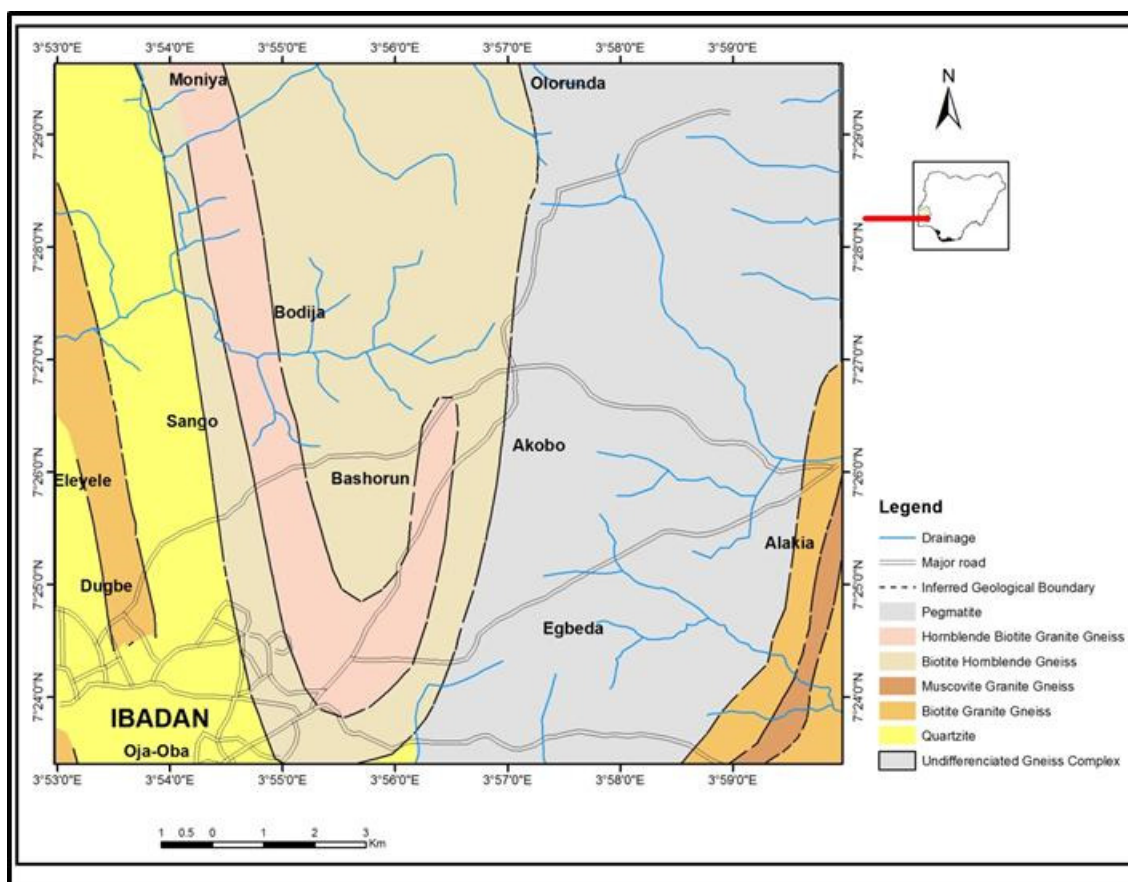Fig. 1: Location Map of the study area with in-set reference map

Fig. 2: Geological map of some areas in Ibadan Metropolis

Methodology
Geochemical Survey

Sample collection - Detailed and intensive geological investigation was carried out in the study area, to study the nature of the rock, topographical expressions, intensity and depth of weathering, and demarcation of lithological contacts on a larger scale than the presently available map. The thickness and intensity of weathering were studied from borehole lithologic, information from river cuttings, and well section road cut/walls. Shallow well logs were studied on the walls of the hand dug wells and heights of the cement concrete rings to protect the walls in the hand dug wells from caving-in and this was useful for determining the thickness of the weathered formation/overburden. Moreover, One hundred and fifty-seven (157) water samples were collected from the study area. At each sampling location, two samples were taken into two different 100 ml rubber bottles-one for cation analysis and the other for anion analysis. The set for cations was acidified using dilute hydrochloric acid (HCl) to stop or stampede further geochemical processes in the sample. These were preserved (refrigerated) prior to analyses. Physico-chemical parameters such as temperature, pH, electrical conductivity (EC) and total dissolved solid (TDS) were determined *in-situ* using WTW pH/91 pH meter and WTW LF/95 conductivity meter. The

sampling points were recorded using a Garmin GPS$_{MAP}$78s GPS.

Analytical Methods

The acidified samples were analyzed using the inductive coupled plasma mass spectrometry (ICP-MS) technique. Atomic Absorption Spectrometry (AAS) has been replaced in many circumstances and application with inductive coupled plasma mass spectrometry (ICP-MS). This was analyzed at Acme Analytical Laboratories, Canada while the un-acidified water samples were sent to PDTF laboratory at the University of Maiduguri, Nigeria for the anions analysis.

Data Analysis

Principal components

Principal components analysis (PCA) attempts to model the total variance of the original data set via the uncorrelated principal components. It is a widely used statistical procedure on mass-spectrometry data for dimension reduction and clustering visualization. Precisely, the PCA will implement and use an orthogonal transformation to identify principal components. In Principal components analysis, the use of percentage of variance to determine the amount of variance that the factors explain was employed. This is used to determine the variance that the factors produced from geochemical species will revealed and the factors that explained the acceptable level of variance will be retained. These levels mainly depend on the classification, applicability and significance of the elemental species. In addition to this, different descriptive analyses where 90% of the data will be used to explain the factors will be adequately employed. Principal components analyses will extract factors since the variance equals the eigenvalues and the size of the eigenvalue is used to determine and retain the number of factors with the largest Eigenvalues. The loading pattern is examined to determine the factor that has the most influence on each variable which will indicate loadings between -1 to +1 specifying the factor that strongly influences the variable. Loadings close to 0 indicate that the factor has a weak influence on the variable while some variables may have high loadings on multiple factors. Unrotated factor loadings are often difficult to interpret while factor rotation simplifies the loading structure, allow easy factor loadings interpretation. Statistical Package for the Social Sciences (SPSS) software will be used for the interpretation.

Geophysical Method

Azimuthal electrical resistivity survey was conducted at Alegongo, Loyola College, Urban Day School and New Garage with a view of mapping the subsurface geology and fracture orientations and to correlate it with the quality of the water using cross square area (CSA). In the CSA study, both Wenner and Schlumberger were integrated (Dey and Morrison, 1979; Loke and Barker, 1996) to accomplish the essence of using these methods. The electrode configuration was rotated about a fixed point at an increment from 0, 45, 90, and 135° corresponding to the E-W, NE-SW, N-S, and NW-SE directions (Fig. 3). Interpretation was done with the aid of 'Origin' software.
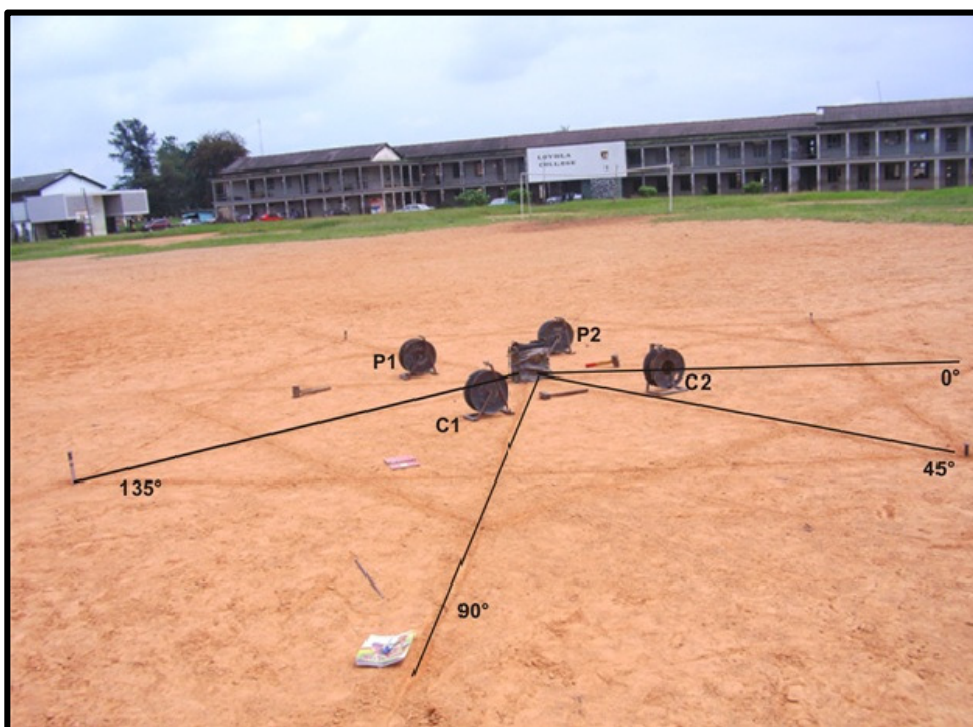
Fig. 3: Electrode arrangement for square array (dc) resistivity method.

Result and Discussion
Azimuthal Resistivity

At Loyola College, the azimuthal resistivity data indicates that a dominant fracture set oriented at 090^0 E-W though with some deviations at about 045^0 while the apparent anisotropy is between 1.19-1.87 and the fracture porosity is 0.02-0.12 (Fig. 4). At Urban Day Secondary School, the dominant fracture set orient at 090^0 E-W and the apparent anisotropy ranges from 1.19-1.93. Secondary porosity is between 0.03-0.10 (Fig. 5). At Alegongo, the dominant fracture set at 090° E-W and the apparent anisotropy ranges between 1.03 and 2.66, the secondary porosity is between 0.03 and 0.99 (Fig. 6). The dominant fracture set at New Garage area is at 045° E-W and the apparent anisotropy ranges from 1.03 and 1.50, the secondary porosity is between 0.01 and 0.36 (Fig. 7). The orientation of these fractures correlated well with the measurements of joints and fractures collected during the mapping exercise. These directions might have a connection to the direction of underground water flow.

Hydro-geologic Interpretation

A piezometric map (Fig. 8) depicting groundwater flow pattern was accomplished by determining the differences between the elevation and water level for the wells. Recharge and discharge zones were apparently identified in the study area. Generally, direction of flow is determined mostly by relative direction of joint and fractures. Observations revealed that, the discharge zones are concentrated along the SW region of the study area, while the recharge zones are scattered. It also pointed to the topography of the static water level. Hence, the direction of underground water flow is along the NW-SE and NE-SW direction.
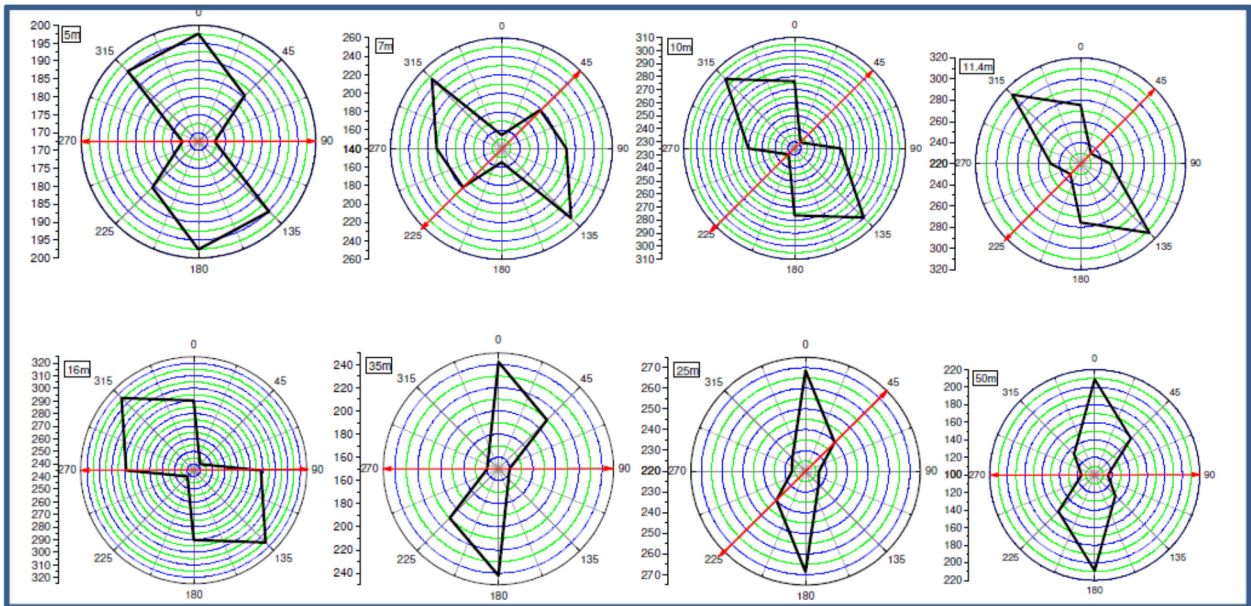
Fig. 4: Electrical resistivity anisotropy polygon with the corresponding depth at Loyola College
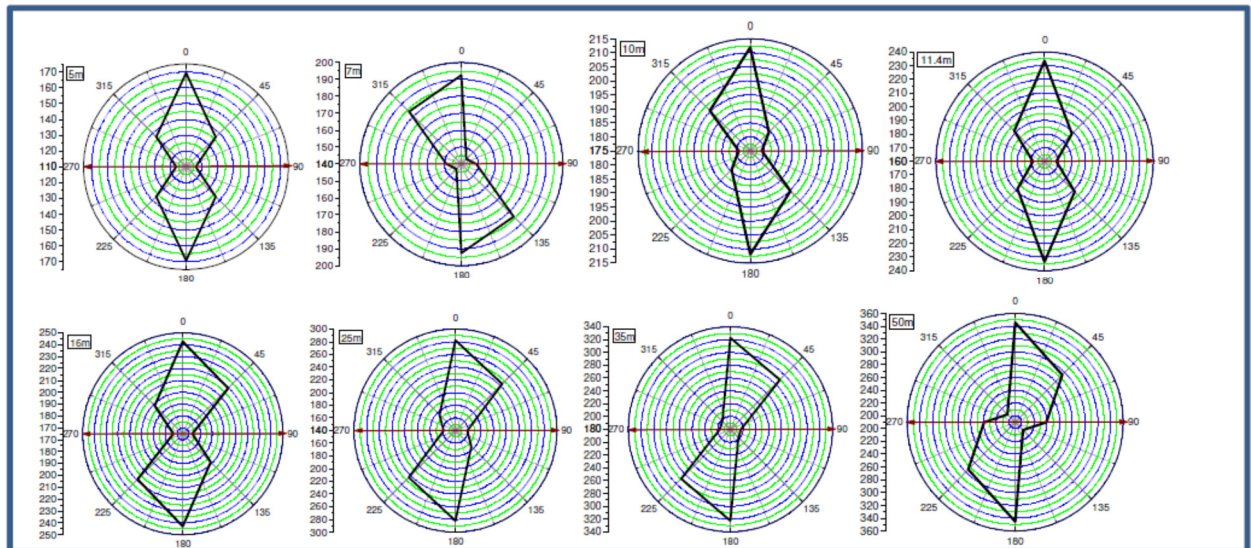

Fig. 5: Electrical resistivity anisotropy polygon with the corresponding depth at Urban Day Secondary School
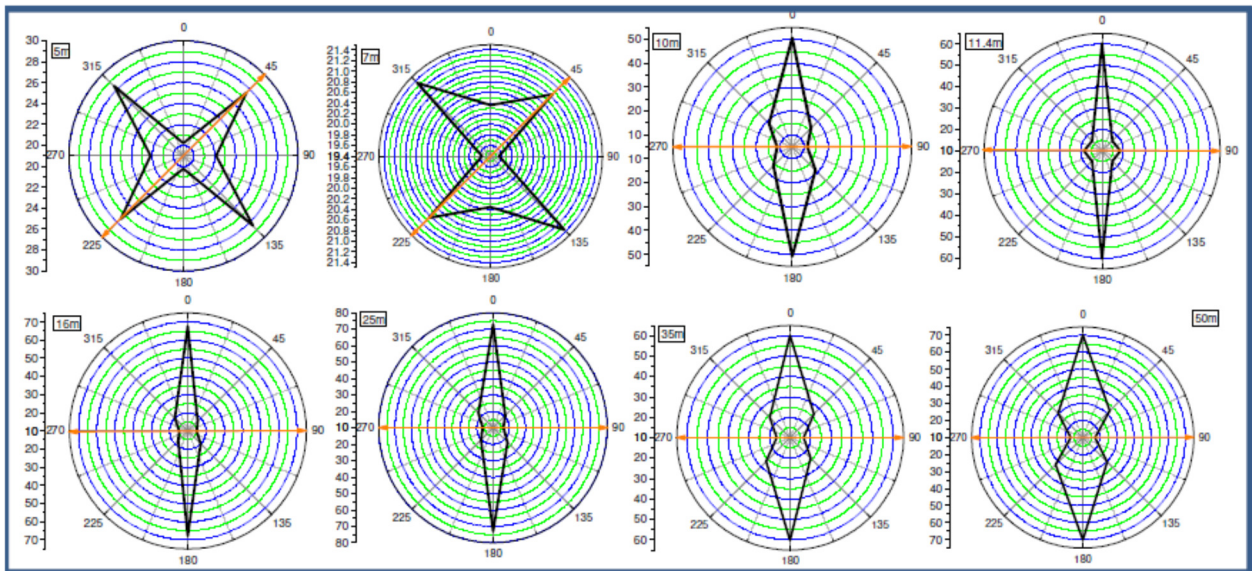
Fig. 6: Electrical resistivity anisotropy polygon with the corresponding depth at Alegongo
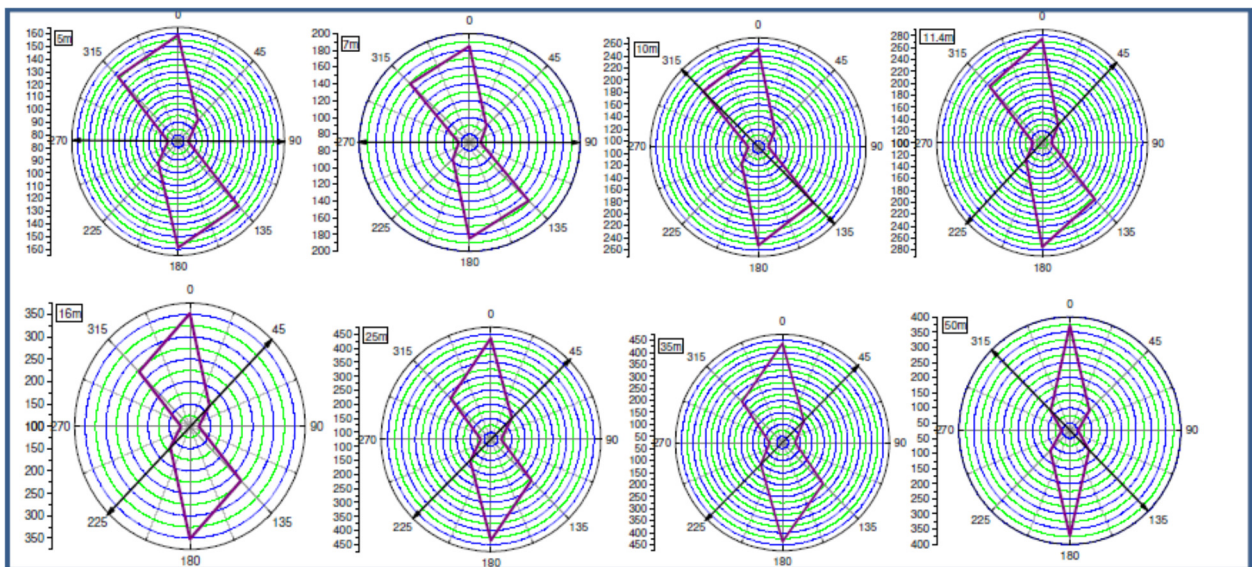
Fig. 7: Electrical resistivity anisotropy polygon with the corresponding depth at New garage
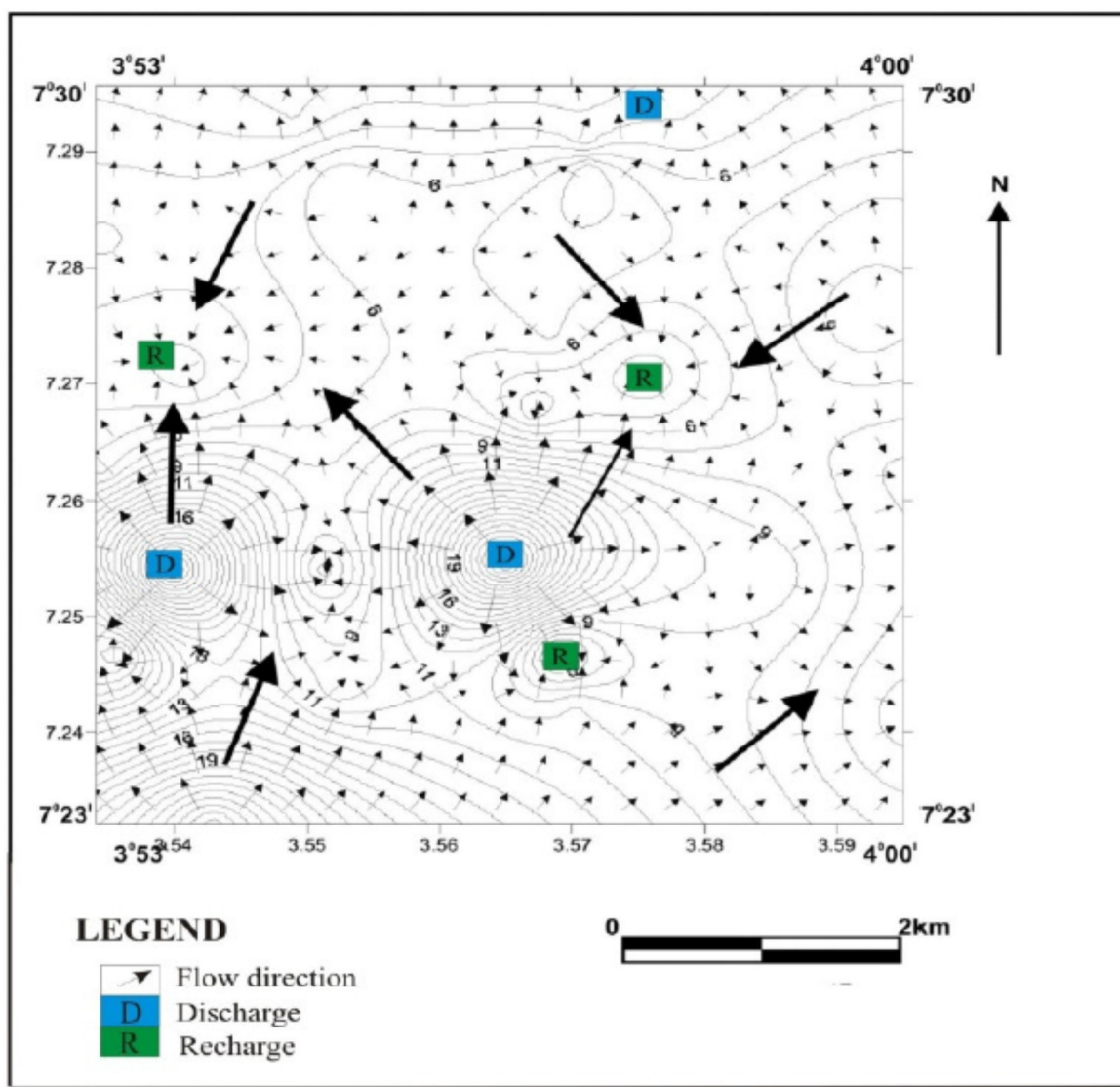
Fig. 8: Piezometric map showing the direction of water flow

Physical Parameters

The most significant physical parameter in water quality tests which regulate all other physical qualities of water. At the course of this study the water temperature varied from 25.6±0.2°C to 29.9±2°C. The maximum temperature (29.9°C) was observed during the month of February 2013 when water temperature was high due to low water level. This is in tandem with the studies of Salve and Hiware, (2006) in other geological terrains.

The pH values in the study area vary from 6.65 - 7.90 suggesting strong acidic to alkaline nature of the groundwater (Table 1). Waters from Alakia, Jamoje and Bada were observed to be slightly acidic to neutral while waters of other areas (Odo-Ona, Olugbogi, Alakia, Oja-Oba, Gbagi market, Agbowo, Ashi Bodija, Gbagi, Akala, Ojoo, Sango, and Elelu) are neutral to alkaline in nature. Since water

qualities are influenced by the interaction of physical and chemical parameters (Uwadiae *et al.,* 2009; Akponine and Ugwumba, 2014). Thus, the pH range obtained in this study is within the acceptable level of 6.0 to 8.5 for culturing in agriculture and potable water for drinking as suggested by (WHO, 2004; USEPA, 2010). High pH levels in water effects ammonia dissolution thereby causes toxic and unionized form that seriously affects aquatic lives.

Electrical conductivity (EC) values were found to vary from 107 μScm^{-1} - 551 μScm^{-1}. However, various values of EC observed within four weeks of sampling with the highest value of 551 μScm^{-1} at high density area with thickly weathered regolith at Odo-Ona area while the lowest value (107 μScm^{-1}) was recorded at Alakia. However, the mean concentration of 214.57 μScm^{-1} was observed. These values were below the standards within the permissible limits of the WHO 2006 (Fig 9).

Total dissolved solids in this present study, the TDS wavered from 20 mgl^{-1} to 36.49 mgl^{-1}. The highest value of total dissolved solids was found in the month of April while the lowest value was observed found during the month of October. This is in support of Alaka, (2014) observation on dissolved solids in water.

Total hardness (TH), an important property indicating the quality of groundwater, is mainly caused by Ca^{2+} and Mg^{2+} and is defined as the sum of their concentrations expressed in mgl^{-1}. Basically, it is the soap consuming property of water. The peculiarity of this property to Ibadan waters accounts for their soap consumption, harsh and unpleasant taste at times. The highest observed concentration for the TH is 563 mgl^{-1} which is above desirable limit (500 mgl^{-1}) of WHO-2004 for total hardness (Table 1).

The Total Alkalinity value ranged between 104.6 - 422 mgl^{-1}. The lowest value was recorded during Oct 2013. Nevertheless, the alkalinity range is 317.4 mgl^{-1}. Alkalinity values were identical (121.50 mgl^{-1}) at about four sites in the study area. Generally, alkalinity values were high in the month of August.

Chemical Properties

Nitrate (NO_3^{2-}): Nitrates concentration is an important tool to measure ground water quality. The concentration ranged from 0.26-12.57 mgl^{-1} with mean and standard deviations of 2.11 mgl^{-1} and 3.26 respectively (Table 1). Nitrates are generally sourced from wastewater disposal and from oxidation of nitrogenous waste products in human and animal excreta, including septic tanks especially where latrines and septic tanks are poorly sited, these can lead to contamination of drinking-water sources with nitrate (Umeham 1992; Umeham and Elekwa, 2005).

Nitrate concentrations is below the WHO standard (45 mgl^{-1}), signifying hygienic potable water. If the NO_3>45 mgl^{-1} symptoms of cyanosis or blue baby syndrome may arise among infants, and development of cancer in adults respectively. All wells showed nitrate concentrations that fall below the WHO and EPA permissible limits. Chloride (Cl^-) controls the salinity mineral salts concentration in water. The salinity of wells investigated was low (Table 1) which can be regarded as safe. However, none of the investigated wells exceeded the WHO and EPA drinking water standard for chloride (250 mgl^{-1}).

Sulphate (SO_4^{2-}) concentrations varied from 0.55 -15.7 mgl^{-1} with mean and standard deviations of 5.40 mgl^{-1} and 4.04,

respectively (Table 1). As with chlorides, sulfates in groundwater are likely to originate from the land surface-mainly from fertilizers ($MgSO_4$, K_2SO_4), debris and cement materials ($CaSO_4$) and behave conservatively in the groundwater system due to high dissolve oxygen levels observed in the study area; thus, SO_4 can be used as an indicator for groundwater contamination as well. Oxidation of naturally occurring sulphide minerals could be another important sulphate source. Generally, sulphate concentrations within the study area are below the WHO and EPA permissible limit.

The overall mean values of phosphates recorded (1.0 mgl^{-1}) were generally low when compared to the WHO (2006) recommended standard of 30 mgl^{-1}and this could also be attributed to same lack of significant farming activities around the study locations. Dilution and movement of water could be as a result of these processes which could not allow degeneration of organic matter content. This study could be attributed to the impact of human activities and other anthropogenic processes that were more evident and increased from one location to the other (Yakubu *et al.* 2014; Ojutiku and Kolo, 2011).

The concentration of carbonates (CO_3^-) which was observed or occur as the highest (432 mgl^{-1}) recorded value in the study area. The concentration of carbonates (CO_3^-) at Odo-Ona, Olugbogi, Jamoje, Oja-Oba, Gbagi market and Akala is higher than the WHO standard 340mgl^{-1} indicating the hardness of the water which might have been derived from carbonates mineral in the migmatite and gneisses (Fig. 9). Meanwhile, other settlements show concentration within the acceptable limit ranging from 142 to 230 mgl^{-1} signifying water qualities that can deteriorate in quality as the geological and environmental factors changes (Fig. 9).

The major element in (mgl^{-1}) ranges from K(1.02-46.02), Ca (13.98-65.55), Mg (4.88-17.97), Al (0.0008-0.35), Na (14.00-103.28) and P (0.05 to 0.06) with mean values of 5.37, 39.74, 12.36, 0.03, 32.98 and 0.03 mgl^{-1} respectively (Table 2). It has an increasing order that revealed Ca>Na>Mg>K>P>Al signifying high concentration of hardness and chlorides (Tables 1& 2). High concentration of K^+ was observed when compared with WHO 2006 standard at Odo-Ona and this could be attributed to the evidence of the high metal. It can also be ascribed to the presence and weathering of the alkali-feldspars (K-feldspar) in the gneissic rock of the area. It also indicates high level of alkalis derived from weathered rock.

Table 1: Descriptive statistics of the physico-chemical characteristics of the water

Parameters	Min	Max	Mean	SD	WHO 2006	EPA 2009
Temp (°C)	25.6	29.9	25.9	7.5	-	-
pH	6.65	7.9	7.2	58.22	6.50-8.50	6.50-8.50
EC (μScm^{-1})	107	551	214.57	112.98	1400	1400
TDS (mgl^{-1})	20	36.49	28.6	4.43	500	500
TH (mgl^{-1})	186	563	371.46	118.43	-	-
Alkalinity (mgl^{-1})	104.6	422	262.39	91.27	-	-
NO_3^{2-} (mgl^{-1})	0.26	12.57	2.1	3.26	45	-
Cl^- (mgl^{-1})	20	60	36.7	13.89	250	-
SO_4^{2-} (mgl^{-1})	0.55	15.07	5.4	4.04	250	-
CO_3^- (mgl^{-1})	142	432	269.9	100.29	240	-
PO_4 (mgl^{-1})	0.24	2.75	1	0.76	30	-
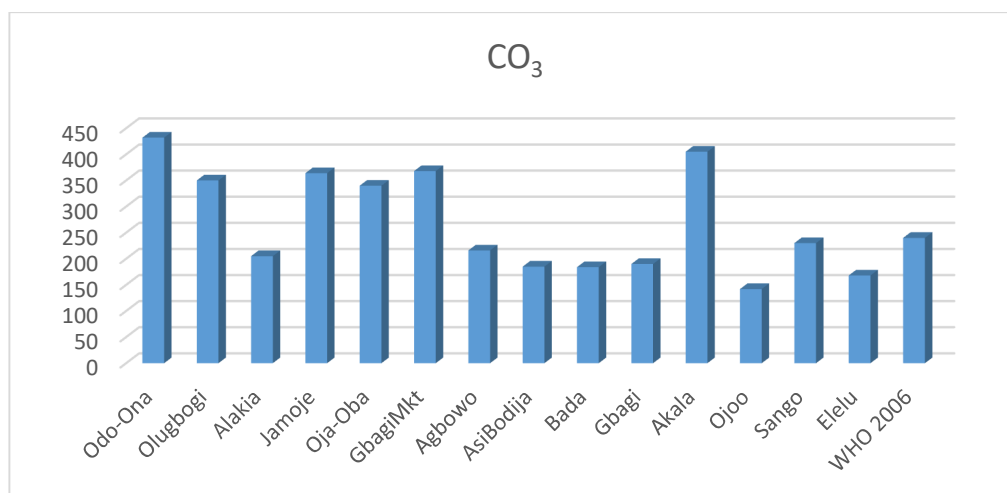
Fig. 9: Comparison of CO_3 concentrations with the WHO standard

Table 2: Major elements with their corresponding WHO values

	Ca	K	Mg	Al	Na	P
Odo-Ona	65.55	46.02	11.77	0.001	103.28	0.01
Olugbogi	61.18	1.06	17.75	0.004	25.15	0.02
Alakia	13.98	2.27	10.31	0.35	30.72	0.04
Jamoje	60.73	1.09	17.97	0.001	25.34	0.01
Oja-Oba	61.84	1.02	18.2	0.005	25.30	0.02
GbagiMkt	62.14	1.08	17.92	0.003	25.83	0.02
Agbowo	17.04	2.41	4.88	0.0009	20.39	0.03
Asi Bodija	17.02	2.36	4.9	0.0008	19.99	0.02
Bada	22.78	5.31	15.06	0.01	64.27	0.01
Gbagi	21.65	3.61	7.01	0.003	41.35	0.05
Akala	61.49	1.6	17.84	0.004	25.32	0.02
Ojoo	18.52	2.58	5.94	0.005	16.33	0.02
Sango	47.46	1.73	14.63	0.005	24.42	0.03
Elelu	24.91	3.1	8.93	0.004	14.00	0.06
WHO 2006	75	12	50	0.15	200	-

Inter-elemental Analysis

Very strong and positive correlation (r=0.9) exist between Na-Sr, K-Sb, CO_3-Ca, EC-Na and pH-NO_3 (Table 3). This signifies the presence of alkalis from alkali-feldspars, the presence and correlation of calcium with carbonates indicate the presence of hardness while the presence of nitrates specifies water with low quality. A strong correlation is also observed between Mg-Ca; Na-K; As-Ca-Mg; Cr-Ca-Mg; Cl-Ca-Mg-As; CO_3-Mg-As-Cl; TOC-Cl, TH-Ca-Cl-CO_3, Alkalinity-TH and EC-K, indicating highly weathered lithology that has good and complete interactions with ground water sources. The released ions as weathering products are involved in various physiochemical reactions, such as oxidation-reduction and ion exchange in the groundwater aquifer system. The correlation of TH-Ca-Cl-CO_3 indicates that hardness in groundwater in mainly due to $CaCl_2$ and $CaCO_3$.

Factor Analysis

The factor analysis model is assumed to provide an adequate representation of the overall variance of the data set. Hence, in the factor matrix only the first three factors are considered (Table 4). Factor-1, which is associated with the variables Ca, K, Na, As, Cl, CO_3, TH and EC explains 33.92% of the variance. This factor reflects the signatures of natural water-rock interaction. Factor-2 accounts for 55.41% of total variance, with the high loading for Co, Cu, Mn, and Zn. The factor explains the effect of anthropogenic sources. The factor-3 explains only 15.12% of variance with the loading for Ni and NO_3. Nitrate has no significant lithologic source affiliation in the study area and it should be associated with the anthropogenic activities. Hence, Factors-1 and 2 are assumed to be indicative of the natural processes, water-rock interaction and anthropogenic effects.

Table 3: Inter-elemental relationship between elements

	Ca	K	Mg	Al	Na	P	As	Co	Cr	Cu	Mn	Ni	Sb	Sr	Zn	Cl	CO3	NO3	SO4	TOC	TH	Alk	PO4	Temp	pH	EC
Ca	1																									
K	0.27	1																								
Mg	0.83	-0.08	1																							
Al	-0.35	-0.08	-0.10	1																						
Na	0.23	0.88	0.08	-0.03	1																					
P	-0.47	-0.19	-0.48	0.18	-0.31	1																				
As	0.89	0.30	0.87	-0.25	0.41	-0.49	1																			
Co	-0.23	0.02	0.14	-0.05	0.39	-0.27	0.09	1																		
Cr	0.78	-0.22	0.72	-0.34	-0.35	-0.07	0.57	-0.39	1																	
Cu	-0.27	0.20	0.04	0.09	0.54	-0.30	0.09	0.93	-0.55	1																
Mn	-0.23	0.01	0.14	-0.05	0.38	-0.29	0.10	1.00	-0.39	0.93	1															
Ni	0.15	-0.22	0.59	-0.05	0.15	-0.34	0.40	0.84	0.12	0.69	0.84	1														
Sb	0.34	0.99	-0.05	-0.10	0.85	-0.18	0.33	-0.08	-0.15	0.11	-0.09	-0.28	1													
Sr	0.40	0.82	0.27	-0.25	0.92	-0.48	0.55	0.49	-0.12	0.58	0.48	0.34	0.79	1												
Zn	0.01	0.73	0.00	0.08	0.86	-0.40	0.25	0.60	-0.50	0.79	0.60	0.31	0.66	0.87	1											
Cl	0.82	0.45	0.74	-0.17	0.48	-0.46	0.80	0.08	0.53	0.08	0.07	0.34	0.47	0.63	0.32	1										
CO3	0.93	0.40	0.72	-0.19	0.35	-0.53	0.81	-0.26	0.62	-0.25	-0.25	0.05	0.46	0.45	0.09	0.87	1									
NO3	0.00	-0.14	0.14	0.17	-0.13	0.28	0.06	0.02	0.13	-0.04	0.01	0.13	-0.15	-0.14	-0.09	-0.34	-0.21	1								
SO4	0.28	0.68	0.03	0.09	0.56	0.03	0.25	-0.16	-0.02	-0.06	-0.17	-0.22	0.69	0.46	0.38	0.45	0.49	-0.08	1							
TOC	0.63	0.03	0.61	0.09	-0.08	-0.46	0.42	-0.22	0.60	-0.20	-0.22	0.15	0.06	0.11	-0.03	0.70	0.67	-0.30	0.19	1						
TH	0.73	0.43	0.54	-0.45	0.38	-0.31	0.61	0.00	0.61	-0.06	-0.02	0.18	0.46	0.56	0.18	0.89	0.78	-0.43	0.48	0.59	1					
Alk	0.44	0.32	0.27	-0.41	0.26	-0.02	0.40	0.03	0.39	-0.05	0.01	0.14	0.33	0.40	0.10	0.68	0.53	-0.49	0.49	0.35	0.79	1				
PO4	0.29	-0.18	0.38	-0.04	-0.18	0.22	0.32	-0.07	0.42	-0.17	-0.08	0.19	-0.17	-0.11	-0.19	0.06	0.18	0.61	0.37	0.03	0.05	0.13	1			
Temp	-0.03	0.06	-0.06	0.02	0.06	-0.19	-0.06	0.05	-0.07	0.08	0.05	0.00	0.05	0.09	0.06	0.38	0.19	-0.93	0.04	0.38	0.44	0.51	-0.59	1		
pH	0.10	-0.09	0.12	-0.07	-0.10	0.12	0.10	-0.09	0.15	-0.13	-0.08	0.00	-0.08	-0.10	-0.11	-0.35	-0.11	0.92	-0.06	-0.32	-0.38	-0.50	0.60	-0.99	1	
EC	0.41	0.86	0.17	-0.15	0.90	-0.40	0.43	0.20	-0.13	0.30	0.19	0.05	0.86	0.86	0.69	0.58	0.55	-0.18	0.58	0.13	0.57	0.36	-0.20	0.13	-0.12	1

Table 4: Varimax rotated factor loading matrix for groundwater chemistry data

Parameters	F-1	F-2	F-3	F-4	F-5	F-6	Communalities
Ca	0.73	-0.61	0.22	0.09	-0.12	-0.15	0.99
K	0.69	0.34	-0.34	0.52	-0.02	-0.04	0.98
Mg	0.57	-0.46	0.60	-0.21	-0.17	0.09	0.98
Al	-0.26	0.17	-0.07	0.06	-0.51	0.77	0.96
Na	0.73	0.56	-0.07	0.33	-0.04	0.00	0.96
P	-0.55	-0.07	-0.20	0.27	0.54	0.29	0.80
As	0.76	-0.32	0.42	0.04	-0.08	-0.05	0.87
Co	0.20	0.72	0.51	-0.37	0.18	0.02	0.99
Cr	0.27	-0.88	0.26	-0.10	0.11	-0.07	0.94
Cu	0.26	0.84	0.37	-0.25	0.01	0.09	0.98
Mn	0.20	0.72	0.52	-0.37	0.15	0.01	0.99
Ni	0.29	0.26	0.75	-0.49	0.11	0.13	0.98
Sb	0.70	0.25	-0.37	0.54	-0.04	-0.06	0.98
Sr	0.85	0.45	0.09	0.17	0.03	-0.12	0.99
Zn	0.58	0.74	0.07	0.16	-0.12	0.08	0.94
Cl	0.92	-0.27	0.03	-0.18	-0.01	0.14	0.98
CO$_3$	0.81	-0.52	-0.01	0.06	-0.17	0.01	0.96
NO$_3$	-0.32	-0.07	0.68	0.60	-0.03	0.09	0.94
SO$_4$	0.56	-0.01	-0.28	0.50	0.24	0.46	0.91
TOC	0.50	-0.53	-0.04	-0.34	-0.34	0.27	0.83
TH	0.85	-0.32	-0.14	-0.17	0.27	-0.04	0.94
Alkalinity	0.64	-0.22	-0.24	-0.22	0.60	0.10	0.94
PO$_4$	-0.01	-0.40	0.56	0.39	0.39	0.36	0.90
Temp	0.30	0.06	-0.61	-0.71	0.02	0.12	0.99
pH	-0.27	-0.14	0.63	0.68	-0.05	-0.17	0.99
EC	0.81	0.31	-0.16	0.31	-0.07	-0.10	0.89
Eigenvalues	8.82	5.59	3.93	3.49	1.49	1.29	
% of Variance	33.92	21.49	15.12	13.44	5.71	4.95	
Cumulative %	33.92	55.41	70.53	83.97	89.68	94.63	

F-1 = Factor 1

Piper Diagram

This diagram consists of two lower triangles that shows the percentage distribution, on the milli-equivalent basis, of the major cations (Ca^{2+}, Mg^{2+}, Na^+ and K^+) and the major anions (SO_4^{2-}, Cl^-, CO_3^{2-} + HCO_3^-) and a diamond shaped part above that summarizes the dominant cations and anions to indicate the final water type (Fig 10). Hence, this diagram shows that most of the groundwater samples fall within Earth Alkaline water and Earth-Alkaline waters (with alkali components).
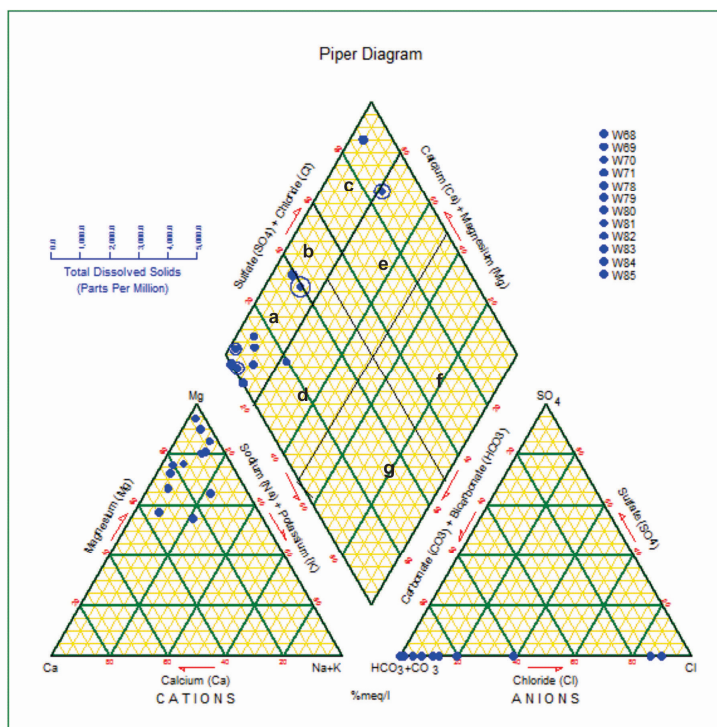
Fig. 10: Hydro-chemical species in the groundwater samples

Conclusion

Major geochemical processes were observed to control the groundwater compositions and relative contributions to the cationic and anionic budgets which diagnostically influence the water quality enhancing its potability or its non-potability for a good health status. Fracture anisotropy revealed from the azimuthal survey (CSA) which is a rotated square array indicates an E–W resultant direction of groundwater flows. The waters of Agbowo and Odo-Ona were found to be slightly acidic. Generally, most water encountered were observed to be hard, this can be linked to the presence of $CaCO_3$ and $MgCO_3$ derived weathered minerals and metamorphic lithologies in the surrounding. Also, vulnerability of the water to increased carbonates (CO_3^{2-}) and hardness is high due to the presence anisotropic fractures. A sound hygienic culture and cleaning procedures should be imbibed in order to ensure safer waters devoid of leachates that can be conducted through fractures into groundwater systems.

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